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ROBERT G. STONE, Editor
Blue Hill Observatory, Harvard University
Milton, Mass., U. S. A.

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## Waves and Currents Recorded by Electromagnetic Barographs

H. BENIOFF AND B. GUTENBERG
Seismological Laboratory, California Institute of Technology, Pasadena

FOR SOME 40 years it has been known as a result of seismograph observations that the ground is never at rest. One of the characteristic types of ground unrest appears in the form of fairly regular wave trains having predominant periods in the range 4 to 10 seconds. These have been observed over the whole earth. Two hypotheses have been suggested as to the origin of these "microseisms". One that they are a result of the action of large surface waves on a steep shore. The other assumes that the ground disturbances are produced by synchronous pressure variations of atmosphere over the ocean acting through the water to the ocean bottom. In order to investigate this hypothesis J. B. Macelwane and J. E. Ramirez built an electromagnetic microbarograph. ([1]) To date they have not published any results bearing on this question.

An electromagnetic microbarograph has been designed by H. Benioff and constructed at this Laboratory. The first observations with this instrument indicated that there is no correlation between microseisms and the various types of atmospheric unrest although we did find a type of atmospheric wave which resembles microseisms ([2]).

The responding element of the microbarograph consists of a permanent magnet moving-conductor type loudspeaker mounted in one of the sides of a sealed container of approximately one-fifth cubic meter capacity. See Figure 1. The effective diameter

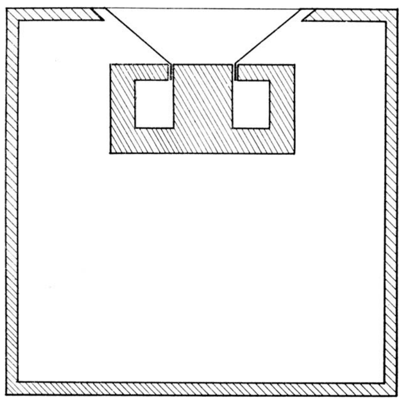

FIG. 1. Schematic diagram of responding element of electromagnetic barometer.

of the loudspeaker cone is six inches. The natural period of vibration of the cone assembly is approximately 150 cycles per second. Hence for frequencies less than 50 cycles per second the cone-displacement is proportional to the atmospheric pressure incre-

[1]J. B. Macelwane and J. E. Ramirez: The Electromagnetic Microbarograph and its Performance, *Trans. Amer. Geophysical Union*, 1938, Vol. I, p. 125.

[2]H. Benioff and B. Gutenberg: An Electromagnetic Microbarograph. Paper presented at the meeting of the Seismological Society of America, April 1, 1938.

ment and the electromotive force induced in the coil is proportional to the rate of change of atmospheric pressure. Output currents are recorded on standard seismograph galvanometric recorders with paper speeds of 60 or 30 mm per min. Three different galvanometers have been tried, having periods of 0.25 sec, 1.2 sec, and 14 sec, respectively. On the whole we now prefer the 1.2 sec galvanometer. With this combination the maximum sensivity is approximately 1mm deflection for a pressure variation of 1 dyne per $cm^{-2}$ or $10^{-6}$ atmosphere (.0008 mm mercury). We believe that this sensitivity is at least one order greater than any which has been used hitherto.

It is possible to use such a high sensitivity at the Seismological Laboratory because of its favorably remote situation from active disturbances and the ground coverage by trees and shrubs. We found, for example, that on the main campus of the California Institute of Technology, local atmospheric disturbances were so great that with this sensitivity, the galvanometer deflections were so large that most of the time the photographic trace was invisible. In view of this behavior we feel that it is extremely important to locate high sensitivity barographs where they will be subject to a minimum of local disturbances.

We have tried moving one instrument to various positions on the laboratory grounds while keeping another fixed at one point for comparison. Some of these positions were a garage with one side open, the basement of the main laboratory with windows and doors open and shut. Except for frequency discrimination and resonance phenomena the results were not greatly affected by position. In other experiments a barograph diaphragm was arranged to communicate with the atmosphere through 20-ft iron pipes, 2″ inside diameter, in order to study conditions above ground in the vicinity of the roof of the laboratory and in the upper branches of trees. The pipe introduced free vibrations having a frequency equivalent to a sound wave length of four times the pipe length. These were effectively damped with a plug of rock wool 12″ long inserted in the open end of the pipe.

A barograph was constructed having a responding element of the pressure gradient type. In order to reduce effects of wind, a plate with ⅛″ round hole was sealed over the free end of the tube and a similar perforated plate was sealed over the diaphragm end. In this way atmospheric variations are communicated to the diaphragm through the two small holes while momentum of currents is largely prevented from acting on the system.

In general, the barograph responds to elastic waves as well as variations in momentum of currents. Consequently in order to differentiate between these two types of movements it was necessary to use two barographs separated by an interval small compared with the wave length of the elastic waves and large compared with linear dimensions of the current variations.

In the early experiments the interval was 30 m and this was later increased to 120 m.

We have identified elastic waves resulting from traffic, gunfire, blasting, surf, possibly earthquakes, and observed more or less regular elastic wave trains resembling microseisms which we call microbaroms.

Our observations on waves resulting from battleship gunfire have been reported in another paper ([3]), in

[3]B. Gutenberg, The Velocity of Sound Waves in the Stratosphere in Southern California, BULLETIN, May, 1939, p. 192 ff.

which sound velocities and temperatures in the stratosphere were calculated. These results agreed with those obtained in Central Europe and Novaya Zemlya.

For some two days in January 5-7, 1939, short wavetrains were recorded having periods approximately ½ to 1 sec and occuring at intervals of approximately 20 seconds (see Fig. 2 a and b). These were never recorded

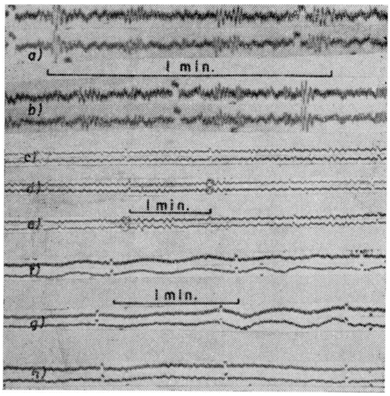


FIG. 2 Microbarograms recorded by two identical instruments separated 30 meters in a), b), f), g), h) and 120 meters in c), d), e). a) and b) January 6, 1939 (largest surf waves in years); c), d) and e) January 25, 1939; f), g) and h) January 8, 1939.

before or after these dates. Ocean-wave records taken at Scripps Institution of Oceanography at La Jolla, Calif., were sent to us by Dr. Eugene La Fond for the same days. He reported that during these days the ocean waves were higher than any time for many months. The period of these waves was approximately 20 sec. We assume therefore that the observed barometric wavetrains are long-period sounds produced by the high waves in some coastal resonant structure. No other cause is suggested by the appearance of the weather map for the days in question.

An earthquake of magnitude 6+ occurred on May 2, 1939 in the Gulf of Lower California some 670 km from Pasadena. Thirty-five minutes later a peculiar series of waves having periods from ½ to 3 sec approximately, began recording as an emergence on our barograph (*). The amplitudes increased gradually to a maximum for about 8 minutes and then decreased slowly, becoming unrecognizable after about 15 minutes from the time of start. Wave groups of this type had not been recorded here before. The time interval between the origin of the earthquake and the beginning of the wave group here, corresponds with a sound-wave travel-time for a distance of approximately 600 km. If we assume therefore that these sound waves were produced by the seismic movements in the vicinity of the epicenter, the first waves were generated at a point approximately 150 km nearer than the epicenter and the last waves at a point approximately the same distance beyond the epicenter. Under this assumption the agreement is all that can be expected. Unfortunately there was only one instrument in operation at the time of this earthquake and we are therefore unable to verify our assumption that the recorded barometric disturbance consisted of pressure waves rather than some local current phenomenon.

Figure 2, c to h, exhibits simultaneous recordings of two identical instruments operating at separate points. The waves shown in c, d and e (see also Fig. 4 b) have periods of approximately ½ to 5 sec and corresponding wave lengths of 0.15 to 1.5 km approximately. They can be observed only when the record is not disturbed. In general they are largest in winter and frequently are too small to be observed in summer. They exhibit no relation to microseisms nor to the barometric conditions in this

*Although the seismic waves were recorded with very large amplitudes on our seismographs the barograph record exhibited no trace of response to the ground movements.

region. No hypothesis as to their origin has yet been suggested. We designate them *microbaroms*.

Figure 2, f, g, h, show trains of fairly regular long period waves of a type which are recorded at frequent intervals. The differences in portions of the records of the two instruments are probably due to local current disturbances. These waves have periods in the range 20 to 200 sec with corresponding wave lengths of 6 to 60 km. We have no hypothesis concerning their origin, although they may be types of atmospheric waves which have been discussed in the literature. ([4])

Wind produces large disturbances which vary rapidly from point to point. In Fig. 3, a and b, are shown the records written by two identical instruments separated by 120 m and show the last hours of a strong wind storm. It will be noted that the rapid oscillations stopped abruptly at about 3:21 on one instrument and 3:24 at the other. This is probably a result of the known fact that turbulence changes rapidly at certain wind velocities. ([5]) During windstorms our pendulum seismographs are practically undisturbed whereas the strain seismograph ([6]) indicates strains of the ground which always accompany the larger disturbance of the barograms produced by winds or convection currents. Fig. 3, c, is a portion of the strain seismogram corresponding in time to the barograms a and b. It is thus apparent that air currents produce strains of the ground even in rock.

[4]H. Lettau: Atmosphärische Turbulenz, Leipzig, 1938, p. 99.

H. Lettau: Klein-meteorologische Erscheinungen am Rande eines Kaltluftsees (Luftseiches), *Veröff. Geophys. Inst. Leipzig*, vol. 10, p. 142, 1938.

C. L. Godske: Review of the theory of extratropical cyclone formation, in: Procés-verbaux des séances de l'Assoc. de Météorologie, Edinbourg 1936, Pt. II, p. 48, 1939.

[5]See, for example, H. Lettau: Atmosphärische Turbulenz, Leipzig, 1938, p. 186.

[6]H. Benioff: A Linear Strain Seismograph, *Seis. Soc. Amer., Bull.*, vol. 25, p. 283, 1935.

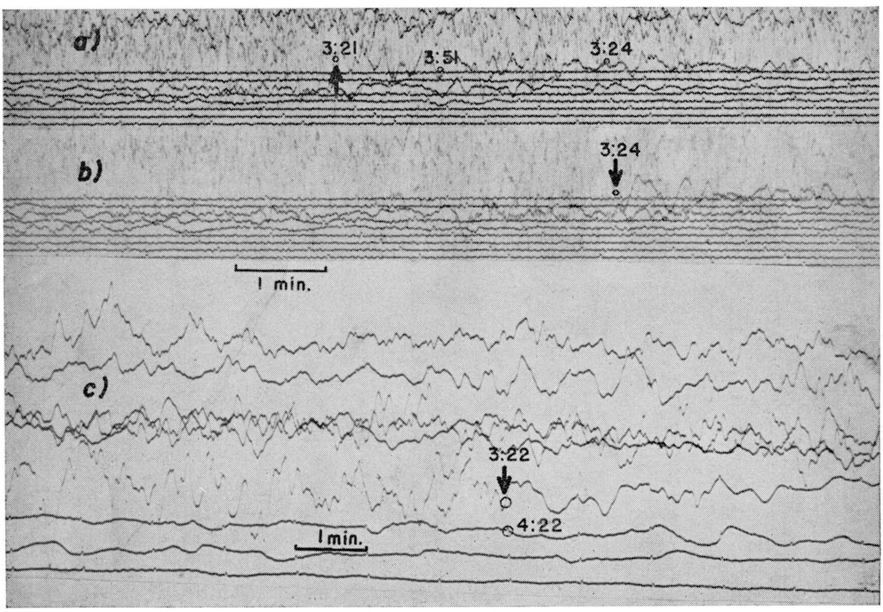


FIG. 3. End of windstorm, February 17, 1939; a) and b) recorded by microbarographs; a) approximately 120 meters south of b); c) is a record written by the Benioff strain seismograph.

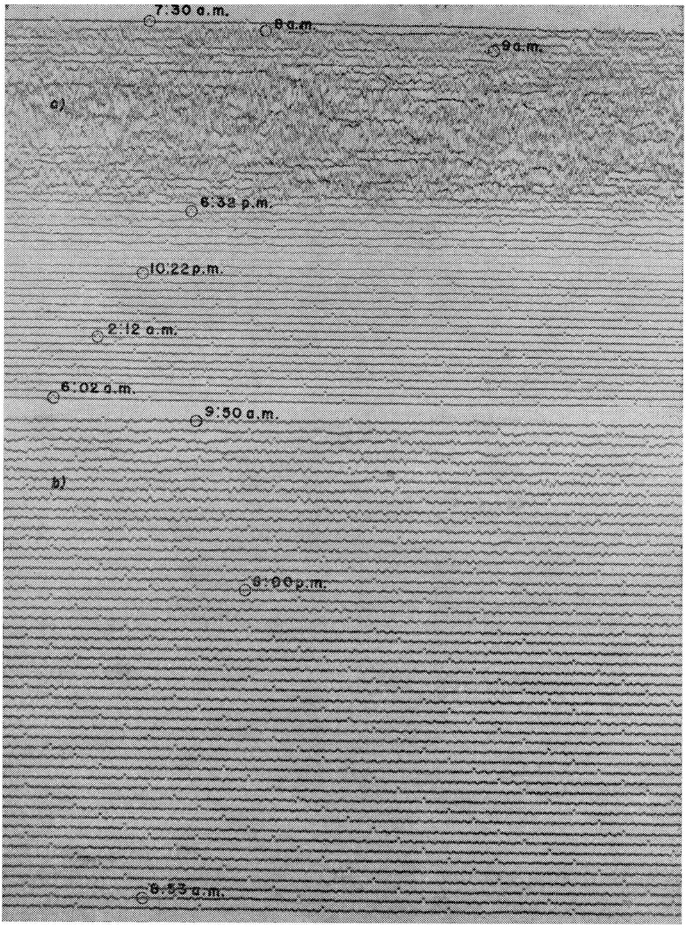


FIG. 4. Typical microbarograms; a) clear day in summer (August 13/14, 1938); b) cloudy day in winter (January 26/27, 1939).

The characteristic daily appearance of our barograms are shown in Fig. 4: a) represents a typical quiet clear summer day and b) represents a cloudy day in winter. The large disturbance on Fig. 4 a) occurring in the daytime is due, we believe, to convection currents resulting from the heating of the ground by insolation. These disturbances vary in magnitude and duration with the season as might be expected. Approximate beginnings and endings of the movements as observed on clear days are shown in Fig. 5. During winter the maximum amplitudes are much smaller than those occurring in summer and on quiet cloudy days they are absent in all seasons. In general our observations show that the convection disturbance increases with increasing height from the ground of the responding element. It is especially bad near a roof. Barographs situated on the roofs of buildings on the campus of the California Institute of Technology proved to be

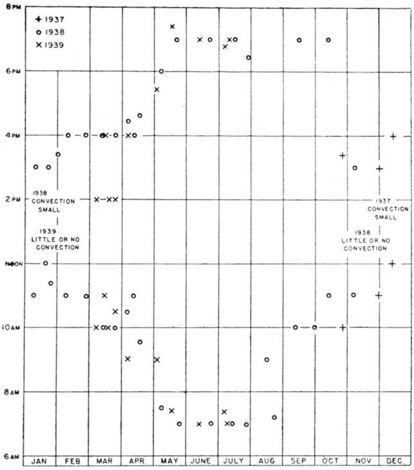


FIGURE 5

useless because of the severe convection disturbance. The least disturbed location which we have found is in shrubbery on the grounds of the Seismological Laboratory.

We have noted that the character of the short period unrest of the barograms is changed sometimes when a cold front passes this region. Fig. 6 is a typical example. According to

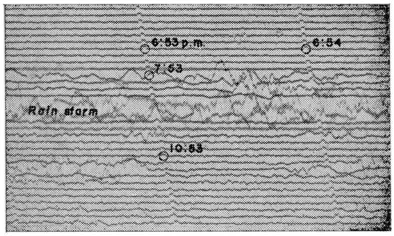


FIGURE 6

FIG. 6. Change in barometric unrest accompanying passage of front, April 12, 1938.

information furnished us by Dr. Krick, of the California Institute of Technology, a cold front passed Burbank some 4 miles west of us between 8:41 and 9:41 p.m.

## The Use of Weather Bureau Data in Flood Control Studies of the Savannah, Ga., Engineer District*

C. F. TRAINOR

Ass't Eng., U. S. Engineer Office, Savannah, Ga.

THE SAVANNAH DISTRICT of the Engineer Department embraces five watersheds, composed of parts of Georgia, South Carolina, North Carolina, and Florida, with a total area of 37,000 square miles. The Savannah River system with 10,579 square miles and the Altamaha River system with 14,403 square miles are the two principal basins in the district and represent 68 per cent of the total area.

In addition to the improvement and maintenance of coastal waterways, harbors, and navigable streams, the Engineer Department has been authorized to study and evolve plans for the control of floods which, in the past, have caused considerable economic losses and, in some instances, involved serious threats to the safety of lives. The Savannah District now has in the process of preparation studies of possible means for the control of floods on the Savannah, Altamaha, and Ogeechee River systems.

A flood control problem may be generally subdivided into three parts; first, the designation of locations in the basin at which conditions during a flood are critical; second, the derivation of the design floods; and third, the type of protection to be employed, such as storage or detention reservoirs, levees, auxiliary bypass channels, or any combination thereof. This paper is principally concerned with the second step—the design flood.

This phase of the work requires a

*Atlanta meeting, April 1939.

complete hydrologic study of the river in question. In connection with this, various data collected and published by the Weather Bureau are indispensable. The two types most essential to any study of this kind are the records of rainfall and river stages. The U. S. Geological Survey has established stream gaging stations at critical points in the Savannah District; however, until recent years, the "Weather Bureau River Stages" was, in many cases, the only source of published data available.

In order to illustrate the major importance of precipitation data, it is necessary to describe in a more or less general manner the various analytic steps which have as their result the determination of the flood control measures to be taken. For this purpose, let us assume the existence of a flood problem at some point on a river.

The first step towards the solution of the flood problem is to determine the critical period, or time of concentration at the end of which the maximum runoff contribution has occurred. This requires a detailed study of past storms and their consequent floods with particular emphasis on the distribution of the storm over the drainage area. The result of this study is the selection of a storm duration period which will place the maximum burden on the drainage system and produce the maximum peak flow at the area to be protected. The selection of the proper runoff factor, which is the ratio of the rainfall appearing in the stream as runoff to the amount which fell, most seriously affects the accuracy of the conclusions made regarding the height of flood to be used as a basis in designing the protective works.

The next problem requiring solution is the selection of the design storm, which represents the maximum precipitation likely to occur over the drainage area under consideration. The nature of this problem readily suggests the possibility of varying opinions regarding the maximum precipitation which may be expected. A discussion of the various systems of reasoning employed in determining the design storm is beyond the scope of this paper. The method used in flood studies of this office consists of a thorough analysis of all storms of record which have occurred in the southeast. Elimination of storms based on such data as the geographical location of the center, the relative intensity and the general path of movement usually narrows the choice to two or three storms. The transposition of the remaining storms over the drainage area under study, and a comparison of the average amounts of rainfall obtained, determine the final selection of the maximum storm.

The maximum average rainfall for the total period of this storm is then distributed in proportion to the daily rainfall of a typical storm which produced a sizeable flood and for which the recorded data are reliable. The duration of the design storm conforms to the period previously selected from the study of the period of concentration which was described above. The conversion of the storm rainfall into terms of runoff is accomplished by manipulation of the mass runoff curve of the typical storm used. Data with which to construct the discharge hydrograph of the design flood are obtained by computing the flow increments from the adjusted mass curve of the previous step. The maximum peak flow is derived from the maximum average daily flow by the application of a suitable peak flow formula, or a factor representing this relationship, provided there are sufficient reliable data available. The maximum peak flow is then accepted as the design flood to be used in the development of the type of protective works required.

From this comparatively brief discussion, it may be seen that the use of precipitation data enters practically each and every step in the derivation of the design flood, which in itself is a major part of any flood control study.

The information published in the "Daily River Stages of Principal Rivers of the United States" has many uses during the course of a flood control study. Generally speaking, it possesses two vital features—length of record and continuity. In many instances, these river stages have been the means of supplementing the stream flow data obtained by other agencies.

In connection with flood control studies, the Engineer Department in cooperation with the Weather Bureau has begun an intensive study of the maximum rainfall problem. The work of the individual Engineer Districts primarily consists of the extraction of rainfall data from the original manuscript records of the Weather Bureau and the compilation of these data in a form suitable for analysis by the Hydro-meteorological section of the Weather Bureau in Washington, D.C. The objectives of the so-called storm studies are to define the limits of transposition of past storms and to present an array of data by which the probable maximum precipitation over a given area may be computed. Such information will be of inestimable value in the selection of the design storm for use in flood control and other studies.

The spirit of cooperation on the part of the Weather Bureau is commendable, not only in its application to our flood study work now in progress, but in the many instances of the past. Regarding the future, there is an additional service which would be of much value to us. At times when it becomes apparent that a river in the district will exceed flood stage, it is desired that some means be devised by which the river stages would be directly communicated to the District office in Savannah. This would enable us to keep timely informed of flood conditions and better to coordinate the field operations for securing essential flood data.

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# Climate and Disease (VII)*

GUY HINSDALE, M.D.
Medical Director, The Greenbrier, White Sulphur Springs, West Va.

## CHAPTER VII

### Climatic Stations for Tuberculosis

IT WAS ONLY ABOUT fifty years ago that we found out what tuberculosis really is. For two thousand years the world was in search of special climates, special foods and medicines, using them in an empiric way with more or less success insofar as the dietetic, hygienic, out-of-door plan of treatment was carried out. These curative measures succeeded then, as they succeed now although preventive measures worthy the name were entirely unknown; but when Robert Koch revealed the tubercle bacillus and determined the various facts in its life history, the result was a gradual, very gradual, dawn which promised better things. As late as 1890 the medical mind did not grasp the necessity for preventive measures.

The late Dr. Henry I. Bowditch, of Boston, was one of the first physicians in America to recognize the value of constant out-of-door life in the treat-

*Continued from the Dec. 1938, BULLETIN, pp. 424-30.